

**Final Progress Report at Penn State University on Penn State Activities  
in the NASA GSFC Transmissive Microshutter Array Technology  
Development Program (NASA NAG5-13320, 04/15/03-10/14/04)**

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**The total amount awarded:** XXXXXXXXXX

## **I. Project Description**

This is a one-year program starting on April 15, 2003 to develop two infrared silicon grisms for Rapid Visible and Infrared Multiple Object Spectrometer (RIVMOS) for observations in 1.1 – 5 microns.

## **II. Major Research Activities**

Our main activities in FY 2003 (April 2003- October 2004):

1. Developed a new etching process with Tetramethyl ammonium hydroxide (TMAH), ammonium persulfate (AP) and a thin silicon dioxide mask (~ 100 nm thickness) and post-processing process
2. implemented UV flood source and ultrasonic etching tank for processing thick silicon pieces for making silicon grisms
3. modeled silicon grism performance with a commercial grating code, GSolver
4. developed software for analyzing wavefront, scattering and efficiency measurements
5. tested and characterized silicon grisms in the lab
6. procured 4 inch silicon disks with a special cutting angle to make silicon grisms with blaze angles from 22 deg degree

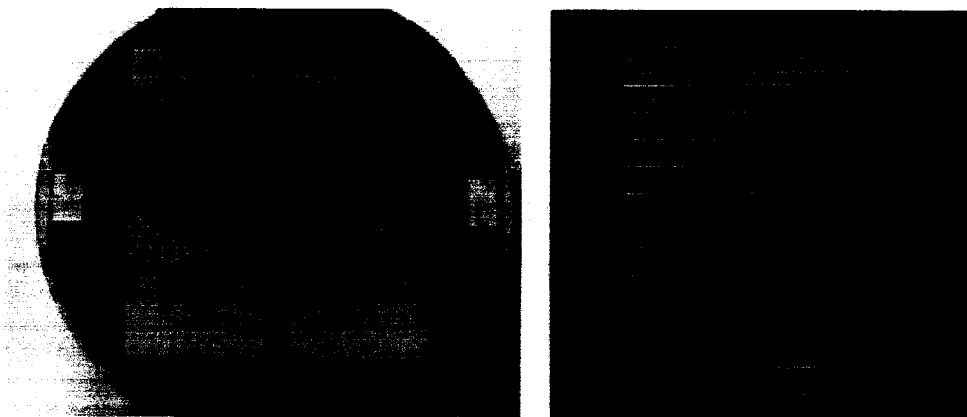


Figure 1. (left): Etched silicon gratings on a 10 mm thick silicon disk with a 30x30 mm<sup>2</sup> grating area for each grating, 7.3  $\mu$ m grooves and a 22 deg. blaze angle. (right): Grating groove profiles under a 100x optical microscope, showing very homogeneous grating grooves without defects.

7. Etched silicon gratings on specially made thick silicon substrates and made silicon grisms

8. cut and polished silicon grisms with  $7.3\ \mu\text{m}$  grooves and a 22 blaze angle and  $30\times 30\ \text{mm}^2$  grating areas

### III. Major Accomplishments and Milestones

1. we made two silicon grisms with  $30\times 30\ \text{mm}^2$  etched grating area, a 22 degree blaze angle and  $7.3\ \mu\text{m}$  grooves for RIVMOS (Figure 1, 2)
2. The TMAH +AP processes have significantly improved the grating surface quality, the rms surface roughness is reduced from 30 nm to less than 3 nm, the minimum rms surface roughness is 0.9 nm
3. The integrated grating scattering light level is reduced from about 10% in the prototype silicon grisms we made at LLNL in 1999 to less than 1% in the near infrared regions
4. We have achieved diffraction-limited wavefront quality (typically rms wavefront error  $\sim 0.035$  waves) for etched silicon gratings with  $30\times 30\ \text{mm}^2$  etched grating area at  $0.6328\ \mu\text{m}$  in reflection
5. We reduced the total ghost intensity to less than 1% of the total intensity, better than commercial gratings, which typically have  $\sim 3\%$  ghost images
6. Grating modeling indicated that we can achieve 80% grating efficiency with silicon grisms with different groove densities (see Figure 3)
7. We found that the pure thin ( $\sim 2000\ \text{\AA}$ ) oxide layer provides excellent etch mask layers for making grating grooves with less than 100  $\mu\text{m}$  pitches.
8. Published 13 refereed and technical papers and 2 abstracts

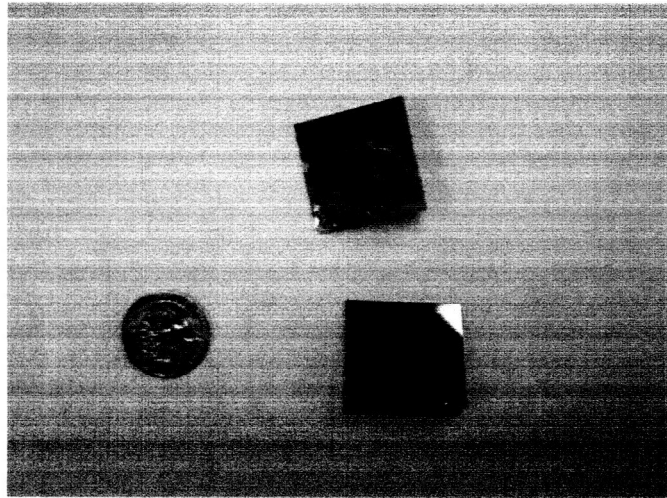


Figure 2. two cut and polished silicon grisms ready for delivering to GSFC. The grating side is covered with baked photoresists for grating surface protection during the grism cutting and polishing.

### IV. Members who involved in the silicon grism development in 2003-2004

Shane Miller, a nanofab engineer, worked on developing new nanofabrication processes for improving grating surface and wavefront quality, developing special tools for making silicon immersion gratings and silicon grisms on thick silicon substrates, fabricating high quality silicon immersion gratings, designing new grating masks for making 4inch and 6 inch size immersion gratings, developing new sputtering processes for improving grating reflectivity with gold coatings and also worked on characterizing optical performance of etched gratings

Dan McDavitt, a research technologist, worked on developing new nanofabrication processes, designing grating masks, characterizing optical performance of etched gratings, identifying potential vendors for providing high quality and large size silicon disks for making large format silicon immersion gratings.

Junfeng Wang, a graduate student, modeled optical performance of silicon gratings and also helped lab testing of silicon gratings, tested silicon grisms in the lab and also the Mt. Wilson 100-inch telescope. He coordinated with a company for cutting and polishing high quality silicon grisms. He also worked on scientific papers reporting our new 2175 Å dust feature discovery among 13  $z = 0.9 - 2.2$  quasar absorbers.

Jerry Friedman, a mechanical engineer, designed all of the mechanical mounts for grating fabrication and testing and also the configuration for making silicon immersion gratings and grisms from the etched silicon gratings on the thick silicon disks.

Jian Liu, a research assistant, analyzed data taken from silicon grating processing data. She also helped grant and travel management.

## V. Technical and Scientific Publications

The following list is the papers or presentation published in the scientific journals and proceedings which are related to this project:

### Papers Published:

1. Ge, J., McDavitt, D.L., Miller, S., Bernecker, J.L., Chakraborty, A., & Wang, J., 2003, "Breakthroughs in Silicon Grism and Immersion Grating Technology at Penn State," Proc. SPIE, 4841, 1006
2. Ge, J., McDavitt, L., Miller, S., & Chakraborty, A., 2003, "High Resolution IR Spectroscopic Surveys for Protoplanetary Systems with Silicon Immersion Gratings," Proc. SPIE, 4835, 172

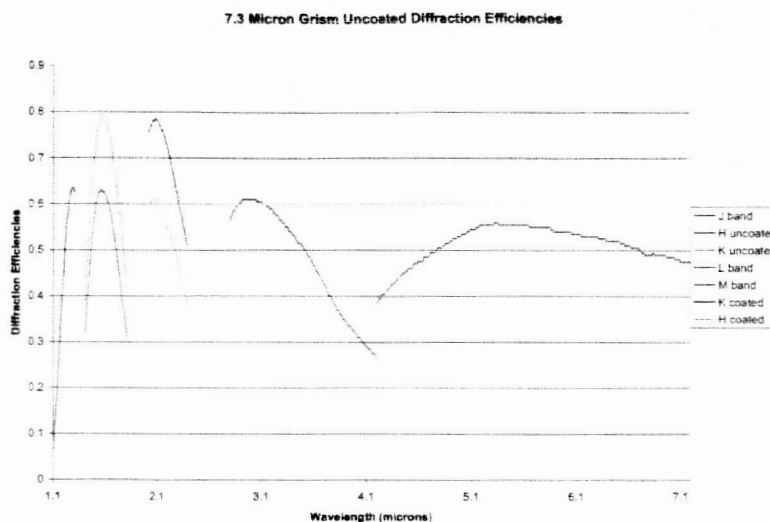


Figure 3. Grating efficiency modeling for the GSFC silicon grisms with 7.3  $\mu\text{m}$  grooves and 22 deg blaze angle. The peak efficiency with a single layer silicon nitride coating is 80%.

3. Ge, J., Bernecker, J.L., McDavitt, D.L., & Miller, S., 2003, "Silicon Anamorphic Immersion Gratings for IR High Resolution Spectroscopy with Future Giant Telescopes," *Proc. SPIE*, 4840, 624
4. Ge, J., Chakraborty, A., Debes, J.H., Ren, D., & Friedman, J., 2003, "Design and Performance of a Versatile Penn State near IR Imager and Spectrograph," *Proc. SPIE*, 4841, 1503
5. Ge, J., Ren, D., Lunine, J.I., Brown, R.H., Yelle, R.V., & Soderblom, L.A., 2003, "Compact High-resolution 3D Imaging Spectrometer for Discovering Oases on Mars," *Proc. SPIE*, 4859, 45
6. Ge, J., Debes, J.H., McDavitt, D.L., Miller, S., & Bernecker, J.L., 2003, "New Generation IR Instrument Components Ready for NGST," *Proc. SPIE*, 4850, 764
7. Debes, J.H., Ge, J., Kuchner, M., & Rogosky, M., 2003, "Using Notch Filter Masks for High Contrast Imaging of Extrasolar Planets", *Proc. SPIE*, 5170, 57
8. Ge, J., Kutyrev, A.S., Dean, B.H., Moseley, H.S.; Woodgate, B.E.; Marx, C., 2003, "The Optical Design of Rapid Infrared-Visible Multi-Object Spectrometer: a NGST Demonstration Instrument," *Proc. SPIE*, 4850, 535
9. Ge, J., Debes, J.H., Watson, A., & Chakraborty, A., 2003, "Imaging Survey for Extra-solar planets with Gaussian-Shaped Pupil Masks," *Proc. SPIE*, 4835, 87
10. Ge, J., McDavitt, D.L., Chakraborty, A., Bernecker, J.L., & Miller, S. 2003, "Adaptive Optics High Resolution IR Spectroscopy with Silicon Grisms and Immersion Gratings," *Proc. SPIE*, 4839, 1124
11. Debes, J.H., & Ge, J., 2003, "High-contrast Imaging for Exo-planet Detection with Gaussian-shaped Pupil Masks," *Proc. SPIE*, 4860, 138
12. Debes, J., & Ge, J., 2004, "High Contrast Imaging with Gaussian Aperture Pupil Masks", *PASP*, 116, 674
13. Debes, J., Ge, J., Kuchner, M., & Rogosky, M., 2004, "Using Notch-Filter Masks for High Contrast Imaging of Extrasolar Planets", *ApJ*, 608, 1095

**Abstracts published:**

1. Ge, J., McDavitt, D., Wang, J., & Miller, S. 2003, "Very High Resolution IR Spectroscopy with a Silicon Anamorphic Immersion Grating," *BAAS*, 203, 3807
2. McDavitt, D., Wang, J., Ge, J., & Miller, S., 2003, "High quality TMAH etched silicon echelle gratings ready for astronomical spectroscopy," *BAAS*, 3809